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A procedure to set tropical cyclone readiness conditions with a high degree of reliability is described. Where possible, threshold values for 90% and/or 95% confidence are given for 50 kt tropical cyclone and typhoon (hurricane) readiness conditions. The methodology used a large number of computer-simulated forecasts for actual typhoons (hurricanes) that passed near Yokosuka, Buckner Bay, Apra Harbor, Cubi Point, or Pearl Harbor. Wind probabilities were computed from these forecasts assuming present-day forecast error characteristics, and were compared to estimates of actual winds. These data were used to establish tropical cyclone condition thresholds at desired levels of confidence as related to wind probability.

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TROPICAL CYCLONE READINESS CONDITIONS SETTING AIDS

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TABLE OF CONTENTS

1. INTRODUCTION

While there have been notable improvements made during the past half century in the field of tropical cyclone forecasting, it is still far from an exact science. Decisions which rely upon these imprecise forecasts are themselves uncertain and therefore carry inherent risks of being incorrect.

The procedure described in the following section can help to minimize these risks by providing a much improved estimate of the <u>probable threat</u> to a specified area by an approaching tropical cyclone. Some of the recent research findings used in the development of this procedure includes:

1) As shown by Jarrell et al. (1978), certain forecasts are inherently more difficult to make and will likely result in larger errors. The degree, or class, of difficulty can be estimated in advance.

2) Crutcher et al. (1982) found that the pattern of distribution of tropical cyclone forecast errors within classes closely approximates a random bivariate normal distribution (normal in both E-W and N-S directions).

3) Jarrell's (1978) development of Tropical Cyclone Strike Probability provides a tested method to estimate the likelihood of a cyclone center passing over, or striking, a specific location.

4) In Wind Probability Forecasting, Jarrell (1981) extends the Strike Probability concepts to estimate the

probability of 50-kt (and 30-kt) winds occurring at a specific location.

5) Cyclone/Hurricane Acceptable Risk Model (CHARM) concept: There is some destructive wind level (e.g., 50 kt) for which preparations must be made and some lower wind level (e.g., 30 kt) which prohibits most preparations (Jarrell and Brand, 1983).

Wind probabilites incorporate the three diverse elements of a standard tropical cyclone forecast (track, maximum wind and wind radii) into a single quantity [detailed in section 2.4] which represents the threat posed by a cyclone. This threat is then used as the basis for decisions regarding setting the proper readiness conditions.* The concept of applying such objective threat estimates to tropical cyclones is a unique feature of a procedure introduced herein as Tropical Cyclone Condition Setting Aids (TCCSA).

CBR Rationale

A cost-benefit ratio (CBR) is a simple powerful tool used in many economic optimization problems. A CBR of .75 (75/100) means that every $.75 in action costs would be expected to return $1.00 in benefits. Correspondingly, a CBR of 1.25 would generally be economic grounds not to act since it represents a situation in which every $1.25 of costs would return only $1.00 in benefits. With perfect information, CBRs can greatly simplify decision making.

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*Typhoon conditions I and II are set when typhoon force winds ($\geq$64kt) are expected within 12 and 24 hours respectively. Typhoon conditions III and IV are set when typhoon force winds are considered possible within 48 and 72 hours respectively. Similar tropical cyclone conditions of readiness relate to stated wind speeds.

With imperfect information, such as weather forecasts, actual occurring weather elements will not be known with certainity in advance. The capability exists to estimate event probabilities, for example, an event like a typhoon strike occurring. There is a rule of thumb which relates this probability to the CBR. This rule states: "In the long run, protective measures should be taken only when the expected losses are greater than the preventative costs." This occurs when the probability of damage exceeds the ratio of the cost of protection to the cost of damage which would occur without protection. This ratio is, of course, the CBR. (In this context the cost-benefit ratio is often referred to as a cost-loss ratio.)

In order to make an objective decision regarding which actions to take (e.g., which if any readiness condition to set), a calculation of the CBR for each condition is needed. Unfortunately, it is impossible to determine a CBR in advance of a tropical cyclone since the CBR is partially determined by the actual course of events, i.e., what damages actually occurred. It is also virtually impossible to make a direct and reliable <u>estimate</u> of a CBR related to condition setting because of the diverse economic considerations of complex actions involved in the setting of a condition. For example, how can we adequately estimate the economic value of human lives, the decrease of our national security due to reduced readiness of military bases or long-term effects of salt water intrusion caused by storm surge, etc?

A dilemma occurs because while a CBR value can't be directly measured or even reliably estimated, it is still useful for an objective analysis. A procedure introduced herein to apply wind probabilities to tropical cyclone conditions or TCCSA (Tropical Cyclone Condition Setting Aids)

solves this dilemma by <u>indirectly</u> estimating the CBR values (see section 3.0). The CBR estimate is determined from the user's selection of a confidence level for correctly setting a certain warning condition. For example, the user may desire to be 95% confident of <u>correctly setting</u> condition I. By this we mean that condition I is actually set 95% of the times that it should be set. By analyzing past cyclones we can determine what CBR value would result in that specified confidence level.

1.1 <u>Objective</u>

The objective of this study was to develop tropical cyclone condition setting aids for 5 specific sites in the Pacific Basin. These sites are:

Apra Harbor, Guam
Buckner Bay, Okinawa, Japan
Pearl Harbor, Hawaii
Subic Bay, Philippines
Yokosuka, Japan

2. METHODOLOGY

The procedure used involved several thousand computer-simulated forecasts for actual typhoons which passed near a selected station. Wind probabilities were computed from these forecasts and then compared to the readiness conditions which subsequently should have been set. This data linked the setting of tropical cyclone conditions to wind probabilities.

2.1 Need to Create Forecasts

The analysis of past tropical cyclone forecasts is a crucial step in the development of the methodology. With the incredibly complex nature of a tropical cyclone, it is necessary to study large numbers of forecasts in order to ensure a high degree of confidence and reliability in the results. Also needed are forecasts made by current methods in order to be certain that the effects are caused by cyclone variabilities and not by changes in forecast methodology. This is complicated by the fact that forecasts from recent tropical cyclones would involve a relatively small population of forecasts due to the small annual number of cyclones threatening any one point of interest. By looking back to 1945, when reliable archives of Pacific tropical cyclone tracks begins, we do obtain a large number of cyclones. However, even if there existed a long archive of forecasts, the methods have evolved, therefore, there would be a relatively small population of forecasts made by current methods. Using older forecast methods would be inappropriate since they do not incorporate today's more advanced forecasting skills.

This problem is surmounted by creating a new set of forecasts to serve as the data base for TCCSA. This solution has two distinct advantages:

1) All forecasts can be made independent, thus multiple forecasts can be made from the same starting point.

2) It is relatively easy to create a large number of forecasts since the forecasts are created by a computer simulation process. This large number of forecasts always reflects the present forecasting skill level.

2.2 Creation of Forecasts

The concept of creating forecasts, or predictions, after we know the outcome is easily justified by noting research by Crutcher et al. (1982). They found that tropical cyclone forecasts can be classified into one of three categories or classes with varying degrees of difficulty. Within each class, the forecast errors follow a bivariate normal distribution with known means, standard deviations, and correlation coefficients.

The procedure to create forecasts consists of six steps. First, a uniformly distributed random number is selected to determine which difficulty class the forecast would come from. This step uses the fact that the conditions (latitude, longitude, motion etc.) attending forecasts partly determine the difficulty class. Thus a larger portion of the uniform probability distribution is allotted to the class preferred under the prevailing conditions. Second, a pair of normally distributed random numbers (R_x, R_y) is drawn to create the two components (E_x, E_y) of a forecast error. The process uses the means (M_x, M_y), standard deviations (S_x, S_y), and correlation coefficient (R) for a 72-hr forecast from the selected difficulty class. The computation is as follows:

$$Ex = M_x + S_x R_x$$
$$Ey = M_y + RS_y R_x + S_y R_y \; (1-R^2)^{1/2}$$

The third step involves generating a CLIPER* (Neumann, 1972) forecast from the same starting point. This forecast is used

*The Pacific versions of CLIPER were used. CLIPER was originally selected because it is fast, objective, competitive in accuracy with the better techniques available today and all its required input information was readily available.

in steps 4 and 5. In step 4, the simulated 72-hr forecast is checked for reasonableness by ensuring that it falls within a 50% probability ellipse around the CLIPER forecast. If the forecast is found to be unreasonable, it is rejected and the process starts over at step 2. This type of reasonableness test is fairly common in operational centers (see JTWC, 1972). Up to 100 tries are made before it is concluded that no reasonable forecast can be simulated and the process moves to the next point along the track. Step 5 involves adding the error components to the 72-hr verifying position and using CLIPER to fit the intermediate track between the starting point and this 72-hr forecast position. The final or 6th step, involves a forecast for maximum winds. Normal random numbers are selected to specify the nowcast and 72-hr maximum wind forecast errors. These are added to the initial and 72-hr verifying maximum winds to create forecasts. Intermediate forecasts are linearly interpolated. The track forecast process is illustrated in Figure 1.

The actual years of typhoon tracks were limited to 1945-1981, the length of record of the TYPHOON analog data set. (A similar limitation applies to Pacific hurricane tracks.) Further limitations were imposed by the availability of actual recorded winds at the stations of interest. Forecasts were simulated along the track of these tropical cyclones at times within the 72 hours preceeding each cyclone's closest point of approach (CPA) to the point of interest. Each foreast error is randomly selected, so by choosing different random errors, we can create new and independent versions of each forecast. This repetitive process allows the creation of a very large number of reasonable forecasts -- about 30,000 for Buckner Bay alone.

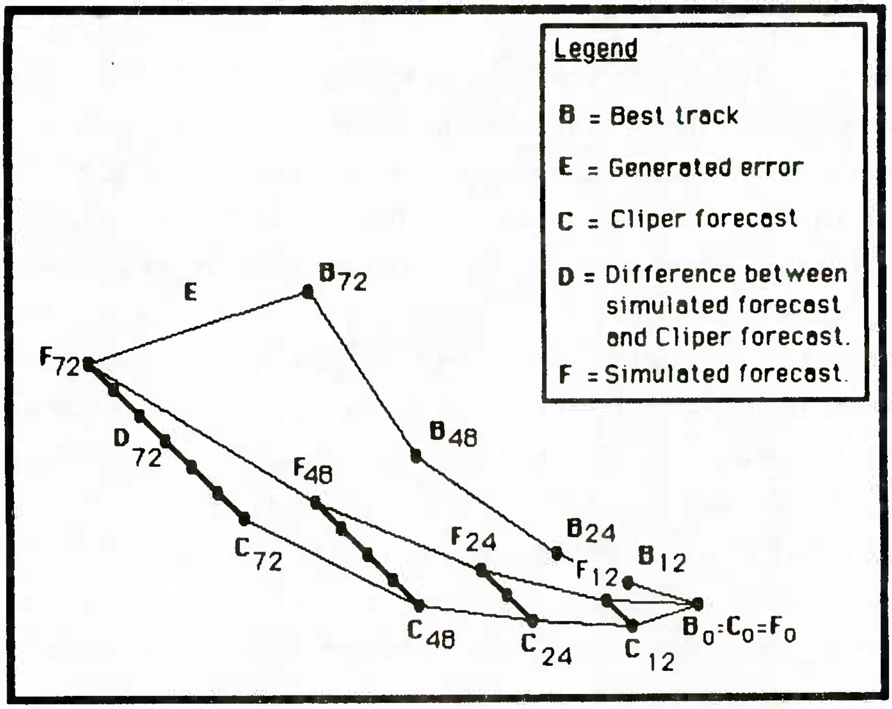

Figure 1. Illustration of the procedure used to simulate a tropical cyclone forecast.

After this large data set of forecasts was created a check was made to ensure that the error distribution was consistent with the current distribution of actual forecast errors. This was done by checking to see if the actual random numbers used were still Guassian (remember they were drawn from a Gaussian distribution, but some were rejected). For all stations the distributions were found to be too peaked (small standard deviation), the result of using too many numbers near the center of the distribution and rejecting too many outlying numbers. This was caused by the requirement for forecasts to fall within a 50% ellipse around the CLIPER forecast. To correct this, a portion of the original forecasts from the interior of the distribution were randomly discarded leaving about one third of the original number.

The final set of several thousand forecasts for each station was again analyzed ensuring that random numbers were representative of a population with zero means, unit standard deviations and zero correlation between pairs. Table 1 summarizes the data by location used in these studies.

Table 1. Summary of Data Used in Station Studies

STATION	YEARS OF REC	# CYCLONES	SIM FCSTS
APRA HARBOR GUAM	1946-76	186	9645
BUCKNER BAY OKNWA.	1945-81	245	13984
SUBIC BAY PHIL.	1956-80	216	10932
YOKOSUKA JAPAN	1953-80	86	8623
PEARL HARB HAWAII	1870-1983	32	2247

2.3 Verification Data

Damage caused by a tropical cyclone can be roughly related to maximum winds observed at the point of interest during passage. An estimate of maximum observed wind at a point was subjectively made based on various sources of information as follows.

Buckner Bay: Observed winds were estimated using an assumed $Vr^{.5}$ = constant profile assymetrically adjusted for forward speed. The estimates were made at hourly intervals along the best track using the archived maximum wind, a maximum wind dependent function for the radius of maximum wind and the instantaneous distance and bearing of the tropical cyclone from Buckner Bay relative to storm heading.

Cubi Point: Actual wind observations were used, but these were adjusted by a direction dependent factor following a study by Woo et al. (1978) of winds in Subic Bay. The attempt was to estimate the maximum wind observed anywhere in the bay as a function of that observed at Cubi Point.

Apra Harbor: Two primary sources of information were used: first, actual hourly wind observations at NAS Agana and second, the publication "Tropical Cyclones Affecting Guam by C. R. Holliday (1978). An estimate was made by adjusting Holliday's reported maximum gust by 77% to approximate a maximum sustained wind. This value was compared to the maximum observed hourly wind and the larger of the two was used. If Holliday's derived maximum as used, it was assigned to the time of occurrence if known, otherwise to the estimated time of closest approach. In most cases, as is

appropriate, Holliday's derived estimate was larger since Apra Harbor is more exposed than Agana and because hourly winds tend not to record the maximum sustained wind.

Yokosuka: Hourly winds at NOCF alone were used to approximate harbor winds. This is probably not a bad approximation since the weather observation point is much more exposed than is the harbor thus compensating (qualitatively) for the fact that hourly observations underestimate the maximum.

Pearl Harbor: Actual observed winds along the south coast of Oahu were used and, additionally, estimates by Shaw (1981) of the peak winds occurring on the south coast were used. Shaw augmented observations with some indirect measurements such as damage reports.

The following notation for tropical cyclone hindcast conditions was adopted:

T1 : winds $\geq$ 64 kt occurred within 12 hr (Condition 1)
T2 : winds $\geq$ 64 kt occurred within 12-24 hr (Condition 2)
T3 : winds $\geq$ 64 kt occurred within 24-48 hr (Condition 3)
T4 : winds $\geq$ 64 kt occurred within 48-72 hr (Condition 4)

S1,S2,S3,S4 : Same with winds $\geq$ 50 kt
G1,G2,G3,G4 : Same with winds $\geq$ 34 kt
D1,D2,D3,D4 : Same with winds $<$ 34 kt

The key to TCCSA is the calibration of a model to utilize threat information on approaching cyclones to determine which warning condition should be set. Calibrating the model on a large data base provides solid evidence of the accuracy and reliability of the procedure.

2.4 Wind Probabilities

The consideration of readiness conditions during the approach of a tropical cyclone is largely based on the probable maximum wind at a specified location, but standard forecasts only predict wind speeds within the cyclone itself. It is left to the resources of each individual site to develop an estimate of probable winds at that site -- a difficult task. However, the use of wind probabilities avoids this difficulty by quantifying the threat of 30-kt and 50-kt winds occurring at a specified location. The wind probabilities used herein and referred as P_{30} and P_{50} are the elapsed time 30- and 50-kt probabilities over the longest available time interval (usually 72 hr). Wind probability is a previously proven concept (Jarrell, 1981). Currently, such probabilities are available for all ocean areas of the world.

It is important not only to set the correct readiness condition but to set it at the proper time. Timing is critical because most physical preparations cannot be performed in winds greater than 30 kt. Therefore, preparations must be started sufficiently in advance of 30 kt winds to allow for their completion. P_{50} is the determining factor in whether or not to set a readiness condition, but the timing of the condition is dictated by P_{30}. The Cyclone/Hurricane Acceptable Risk Model (CHARM) (see figure 2 and Jarrell and Brand, 1983) is based on these considerations and best estimates of appropriate CBR values for each condition. Each combination of P_{30} and P_{50} determines which warning condition (if any) should be set at that time. According to figure 2, if $P_{30} = .80$ and $P_{50} = .30$, then T2 should be set. The positions of the thresholds lines between the conditions are determined by CBRs. Good estimates of CBRs are therefore needed to ensure proper conditions.

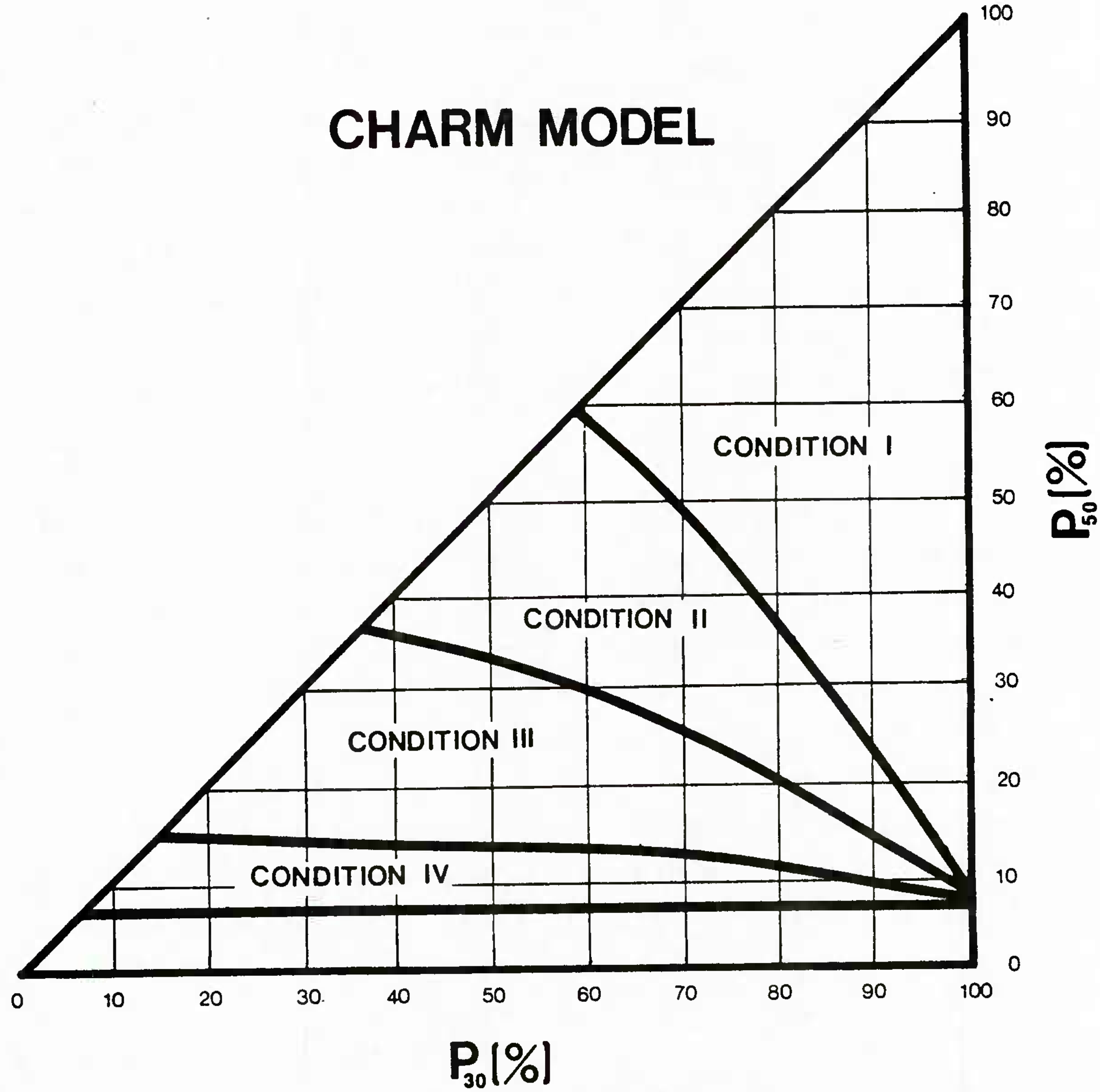

Figure 2. The form of a decision nomograph based on the CHARM model is shown. The actual position of the threshold lines between condition zones is arbitrary.

3. SELECTION OF CBR GUIDELINES

Through a comparison of a large number of wind probatility forecasts, with the hindsight estimates of actual conditions, threshold or guideline CBRs can be related to a confidence level. This means that even though it is virtually impossible to directly estimate these guideline values, we may still obtain a set of values of known reliability. In fact, the user's selected degree of reliability, i.e., confidence in percent for each particular condition, determines the guideline CBR values which in turn provide the required confidence levels.

To clarify the meaning of these confidence levels, a 95% (or .95) confidence level for T1 means that condition T1 would be set in at least 95% of the occassions that warranted it, or correspondingly, that T1 would not be set on less than 5% of the instances that it should have been set. A 95% T1 confidence level does not mean that typhoon force winds occur within 12 hours in 95% of the occasions that T1 is set. It must be noted that higher confidence levels necessarily result in higher overwarning rates, a fact which explains why it is unrealistic to expect 100% confidence levels.

Figure 3 shows the initial selection of a guideline value for hurricane condition II at Key West (Kostyshack and Jarrell, 1984). Each point (·) represents the P_{30}, P_{50} values for one forecast of a cyclone, which in hindsight we know to have caused hurricane force or greater winds at Key West not less than 12 hours nor more than 24 hours subsequent. The curved lines represent CBR values for 24 hours from 0.10 (coincident with P_{50} = 10% at the far left) to 1.00 (upper right curved line). At the action

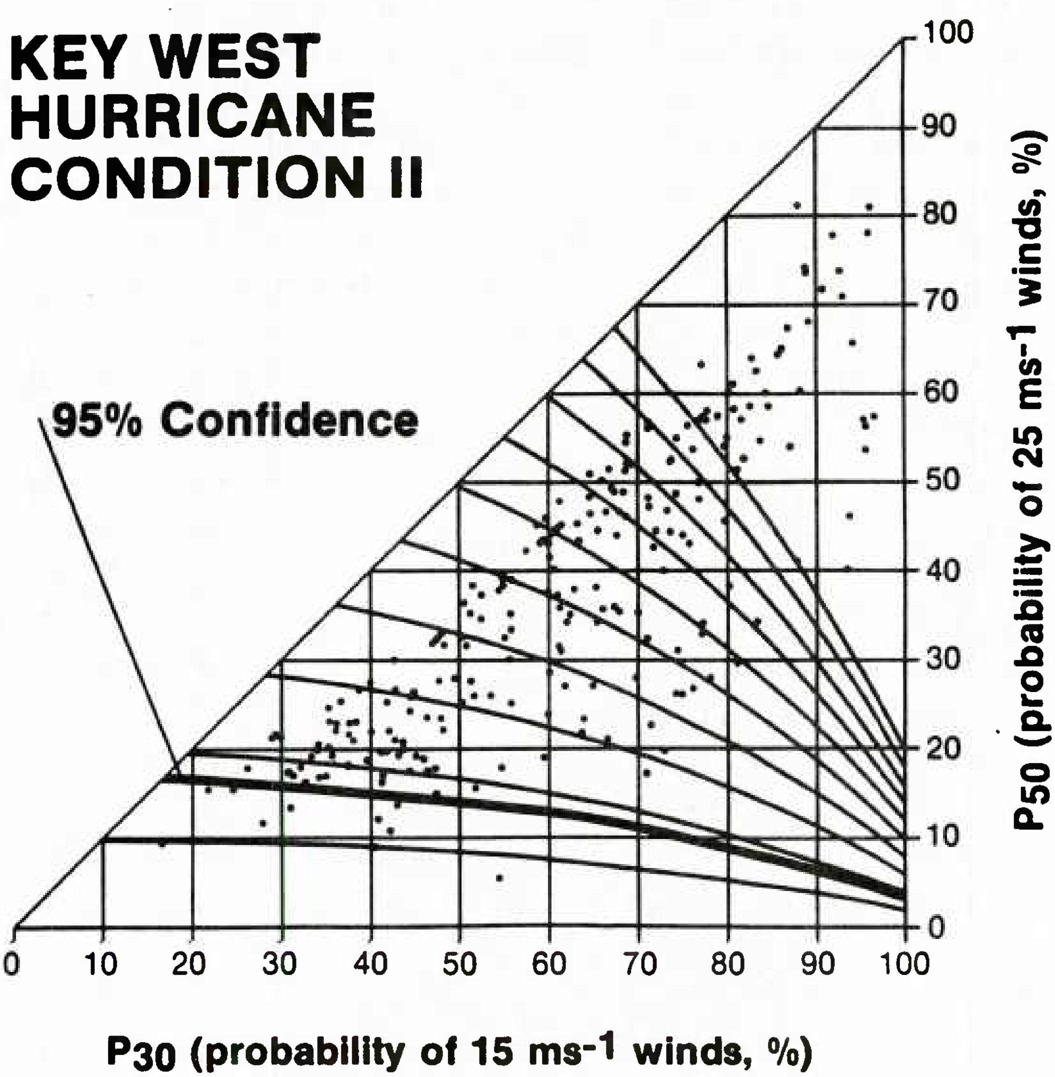

Figure 3. The scatter of P_{30} vs P_{50} plots 12-24 hours prior to hurricane winds at Key West is shown. The curved lines are CBR values for 24 hours before hurricane force winds ranging from 0.10 (coincident with 10% P_{50} line on lower left) to 1.00 (last curved line, upper right).

threshold, the CBR is equal to the level of threat (probability) of the damaging event occurring; hence, the two terms can be used interchangeably when referencing a threshold. Hereafter, level of threat (Z) will be used exclusively. In figure 3 level of threat of .17 (heavy curved line) allows a 95% confidence. The points above and to the right of the curve comprise the 95% frequency in which tropical storm condition II would be correctly set while the 5% failure rate is evident by the small number of points below that same curve. The actual counting is done by computer tabulations. (Although a level of threat of 0.17 was the threshold value selected for the example above as well as the example to follow, actual values vary widely as will be seen later.)

The foregoing explanation somewhat over simplifies the problem by focusing on only those cases where storm force winds arrived 12 to 24 hours subsequent. The problem becomes apparent when we select a threshold value and begin to apply it. For example the frequency with which a level of threat threshold of 0.17 would have been exceeded at Buckner Bay is shown in the center column of Table 2 stratified by lead time to arrival of storm force winds. Z_t is the level of threat estimated at time t. Z_t is a function of the 30- and 50-kt wind probabilities over an elapsed time of 72 hr.

Table 2. Example of observation of one 95% time line for Buckner Bay

t	$P(Z_t>0.17)$	$P(Z_k>0.17, k=t \text{ to } 72)$
6 hrs	77.5	>99.9
12 hrs	81.6	>99.9
18 hrs	72.5	99.9
24 hrs	72.1	99.8
30 hrs	84.8	99.1
36 hrs	70.3	94.3
42 hrs	65.9	80.6
48 hrs	50.0	66.1
54 hrs	48.8	55.1
60 hrs	24.2	28.8
66 hrs	21.1	21.1
72 hrs	0.0	0.0

The right hand column is an estimate of the probability that a threshold of 0.17 would be exceeded at any lead time in excess of t hours. The distinction is that if we were to select 0.17 as our 12- to 24-hr threshold value it would have been exceeded too early virtually everytime (99.1%). At a 95% confidence level, 0.17 is approximately the correct confidence level for the 36-hr point (since the 94.3% is very near 95%). The summation process resulting in the right hand column treats the probabilities as serially dependent even though in this simulation much of the interdependence was removed by the error generation algorithm.

The probability of a given threshold (T) being exceeded at time t + 6 hr, or at time t, is given by:

$$P(Z_{t+6}>T \text{ or } Z_t>T)=P(Z_{t+6}>T)+ P(Z_t>T)(1.0-Pc)$$

where Pc is the conditional probability that the specified threshold will be exceeded, given that it was exceeded 6 hours

earlier. These conditional probabilities (Pc) which are dependent on geography as well as the size of the threshold were estimated using all JTWC forecasts for 1982. Notice that if Pc is near unity that the summation process is unnecessary; this is, in effect, the assumption which was applied in the Atlantic studies. Although showing considerable variation, a mean value of Pc for these sites is about 0.75.

By creating an approximate exceedance probability table for possible values of thresholds against time, one can readily select a threshold which provides the desired confidence at each lead time. This has the desired side benefit of producing a "clock" or an "arrival time" based on a specified confidence level. For example, a 95% confidence level typhoon force wind "clock" might be referred to as a "worst case clock", and values extracted from it could be viewed thusly: "In the worst case, typhoon force winds could arrive at this point within x hours". Figure 4 represents a 95% confidence typhoon force wind clock for Buckner Bay.

Use of CHARM Clock

Figure 4 is a CHARM clock for worst case (5%) arrival time of typhoon force winds. To use the CHARM clock, enter with the largest values of 30 kt and 50 kt wind probabilities. These are the elapsed time values usually over a 72 hour period. They are found as the far right two digits in the appropriate lines for your station in the tropical cyclone wind probability message. Read off the worst case arrival time for either 50-kt or typhoon force winds. Figure 5 illustrates the use of these diagrams for a hypothetical situation. This illustration results in a worst case lead time of 42 hrs which means the time to set condition III may be at hand (if condition III is not already in effect). Any action which requires

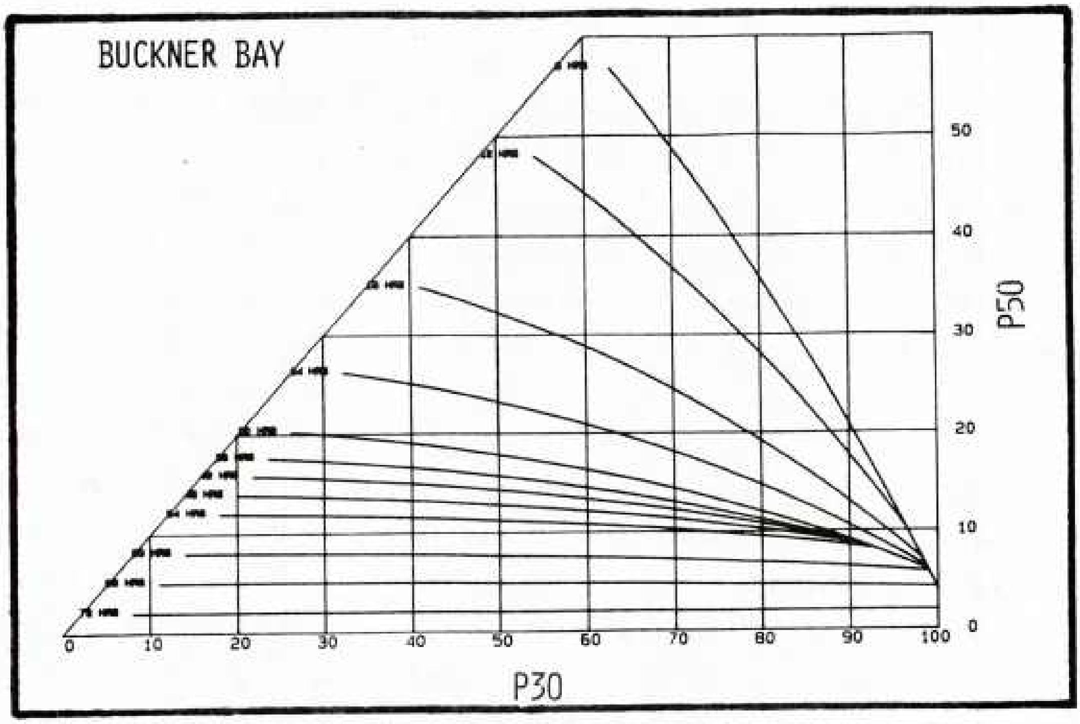

Figure 4. CHARM clock representation for typhoon force winds at Buckner Bay, Okinawa. Time lines represent worst case (5%) arrival time of typhoon force winds. P30 and P50 are elapsed time 30-and 50-kt wind probabilities.

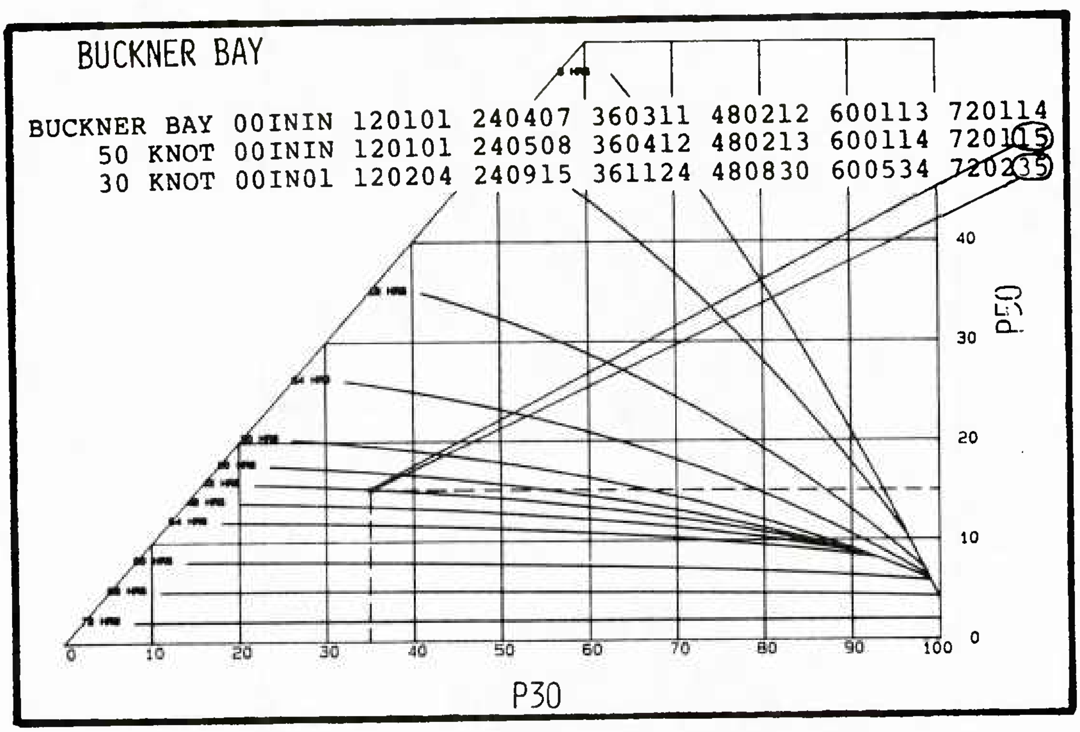

Figure 5. Same diagram as figure 4 except superimposed is a hypothetical wind probability message. Circled numbers are the 30-and 50-kt elapsed time wind probabilities. The result can be read as "in the worst case, typhoon force winds can arrive within 42 hours".

42 hr and must be completed should be started. Since these time estimates are worst case they purposely underestimate the remaining lead time in all but the worst case. For this reason one should not feel compelled to rush to setting condition III because the CHARM clock indicates that there may be as little as 48-hr lead time to destructive winds. Rather this should be viewed as a necessary condition prior to setting a condition, but <u>not</u> a sufficient reason for setting it. The prudent commanding officer <u>should consider</u> setting the indicated condition but he will often delay it. As a median, these worst case lead times will underestimate the actual lead time by about 12 hr and as much as 18 hr at the long end of the time scale (72 hours). By using up half of that cushion one can usually avoid setting conditions in the nightime hours when their effectiveness is marginal in any case. Notwithstanding the above, to be 95% certain of having the required action hours in each condition, one must allow for the worst case. Thus it is not prudent to routinely use up the cushion unless the allowed lead time is not needed because of some existing special circumstances.

In the following sections each station will be discussed with respect to the following:

a. Exposure to strong winds
b. Data used, limitations
c. Results and condition Nomographs or (CHARM clocks).

4. APRA HARBOR, GUAM

4.1 Discussion of Harbor Exposure

The following summary description by Brand and Blelloch (1976) sums up the salient facts about the harbor nicely:

"There are no aspects of Apra Harbor that recommend it as a typhoon haven. Typhoon Karen (November, 1962) gave Apra Harbor sustained winds of 150 Kt! The surrounding topography is low and does not provide an extensive wind break. The harbor entrance is open to the west and is in close proximity to the berths and moorings in the outer harbor. Consequently, westerly winds and seas associated with the typhoon passage have a devastating effect within the harbor.

In the past, all U. S. Navy ships capable have sortied from the harbor upon the approach of a typhoon. Additionally, the Port Operations Officer desires that ships not use Apra Harbor as a typhoon haven since the harbor's and NAVSHIPREPFAC Guam's yard and service craft occupy virtually all desirable berths in the harbor during typhoon conditions."

We have interpreted the typhoon haven study and our own experience with Apra harbor to indicate that evacuation is necessary for winds in excess of 50 kt.

4.2 Discussion of Data Sets

The typhoons passing Guam are better documented than for perhaps any other Western Pacific location largely because of the fine publication "Tropical Cyclones Affecting Guam" by C.R. Holliday (1975). That publication provided a basis for our estimate of the maximum winds at Apra harbor with each passage. Table 3 lists the tropical cyclones that caused at least gale force winds over the period 1946 to 1976 and an estimate of the maximum winds observed at Apra Harbor.

Table 3. Summary of Tropical Cyclones Affecting Apra Harbor.

Name	Date	Winds	Name	Date	Winds
unnamed	9/20/46	60 kt	Wendy	7/11/63	36 kt
Agnes	11/14/48	39 kt	Susan	12/24/63	50 kt
Allyn	11/17/49	75 kt	Sally	9/05/64	50 kt
Doris	5/09/50	45 kt	Gilda	11/13/67	43 kt
Marge	8/11/51	39 kt	Jean	4/11/68	36 kt
Hester	12/31/52	50 kt	Irma	10/22/68	46 kt
Irma	2/21/53	39 kt	Judy	10/27/68	36 kt
Nina	8/10/53	41 kt	Ora	11/23/68	54 kt
Alice	10/14/53	40 kt	Phyllis	1/22/69	34 kt
Lorna	9/14/54	36 kt	Amy	5/03/71	43 kt
Lola	11/15/57	71 kt	Mary	8/12/74	39 kt
Nancy	9/11/61	36 kt	June	11/19/75	50 kt
Karen	11/11/62	>120 kt	Pamela	5/21/76	>120 kt
Olive	4/29/63	64 kt			

The expected frequency of major disasters has been on the order of once per decade with typhoon force sustained winds being observed once every 6 years or so. If one evacuates only for tropical cyclones causing 50-kt winds or greater this would occur about once every two years. Since a reasonable amount of over-warning is required to be sure to catch all those necessary cases, it is estimated that evacuation occurs on the average at least once per year and perhaps as high as twice per year. This study has as its objective to provide guidance that will permit condition setting with a high degree of confidence without excessive overwarning.

4.3 Results

Tropical cyclones passing Guam are less homogeneous than those passing points farther north and west. They are dominated in numbers by forming storms and storms embedded in the deep easterlies. Consequently the major sources of impact uncertainty comes from the size and strength forecasts as opposed to track and speed forecasts. Included in the broad spectrum of developing tropical cyclones which pass Guam are occasional typhoons just reaching their peak of severity as they pass. Examples are Karen (1962) and Pamela (1976) which made a direct hit on Guam. Amy (1971) is an example of a typhoon at its peak which barely missed. Because, in the mean, passing tropical cyclones are weak and because of terrain influence, wind probabilities for Agana are low compared to other points studied. As a consequence, low threshold probabilities are required to cover 95% of the actual damage cases. Nevertheless the performance of this type "CHARM clock" should be satisfactory.

Two sets of 95% or worst case arrival time winds were developed, one for 50-kt winds (figure 6) and one for typhoon force winds (figure 7). The former is expected to serve as a guide to timing harbor evacuation while the latter is intended for more general typhoon condition setting. An attempt to apply them simultaneously will lead to minor ambiguities. For example, a P_{30}, P_{50} pair of (30,10) would lead to 50-kt tropical cyclone condition II and typhoon condition III. Higher probabilities will be required for a typhoon condition than for a lesser tropical cyclone condition of the same number. Deciding which to use can usually be based on the existing (as opposed to forecast) tropical cyclone intensity. If the tropical cyclone is a typhoon, or nearly so, on a steady or increasing trend, the typhoon condition is appropriate. If the

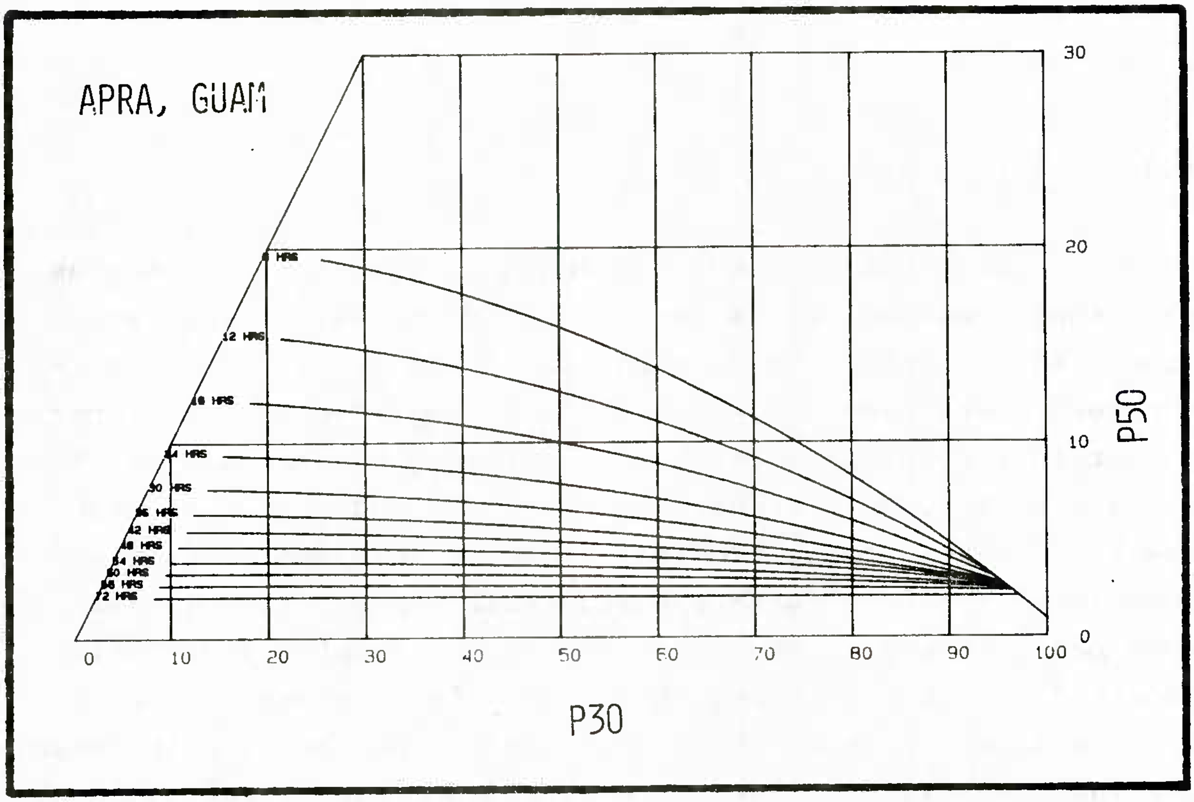

Figure 6. Apra Harbor, Guam CHARM clock for worst case (5%) arrival time of 50-kt (or greater) winds.

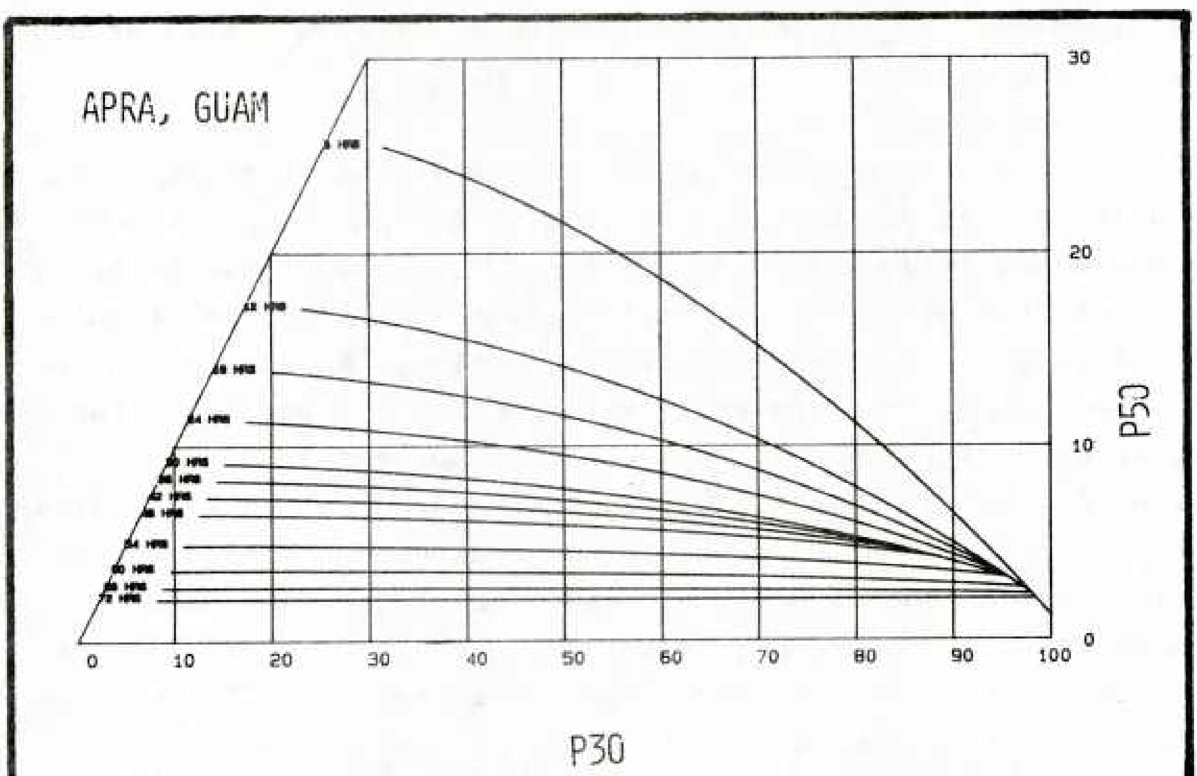

Figure 7. Apra Harbor, Guam CHARM clock for worst case (5%) arrival time of typhoon force winds.

cyclone is a depression or a weak tropical storm not expected to be a typhoon at CPA, the 50-kt tropical cyclone condition is appropriate. Most actions and the worst case time lines are about the same for the early conditions (III and IV) so the question most directly relates to conditions I and II and therefore a nowcast or a short range forecast is involved.

4.4 Overwarning

Table 4 shows overwarning rates for events in the simulated data set when various typhoon or 50-kt tropical cyclon conditions would have been set on the basis of exceeded threshold values. Thus the use of TCCSA for setting typhoon conditions I through IV results in very reasonable overwarning rates of 1.6, 3.5, 10.0 and 32.3 respectively. Use of TCCSA for 50-kt tropical cyclone conditions I through IV will result in somewhat better rates of 0.9, 3.2, 7.3, and 19.0 respectively.

Table 4. Overwarning rates for occasions where typhoon and 50-kt tropical cyclone conditions would have been recommended

	Typhoon Condition					50-kt TC Condition			
ACTUAL	I	II	III	IV	ACTUAL	I	II	III	IV
>63 kt	1.6	3.5	9.0	32.3	>63 kt	1.6	4.9	13.3	99.0
>50 kt	0.9	2.1	5.7	11.5	≥50 kt	0.9	3.2	7.3	19.0
≥34 kt	0.3	0.8	2.2	3.3	≥34 kt	0.3	1.2	2.7	3.8

To put the overwarning rate in perspective, if a sortie is ordered on 50-kt tropical cyclone condition II, a sortie would be ordered unnecessarily three times (3.2 in Table 4) for each time it was (in hindsight) necessary.

5. BUCKNER BAY, OKINAWA

5.1 Discussions of Harbor Exposure

The following summary description by Brand and Blelloch (1976) sums up the havenlike characteristics of Buckner Bay.

"The conclusion reached by this study is that Buckner Bay is not considered to be a haven during typhoon conditions. The lack of extensive protection from wind due to the relatively low topography of the surrounding land mass and the exposure of the ships to wind and seas with any easterly component severely limits Buckner Bay as a storm refuge.

It is recommended that all Navy ships capable take action to evade at sea when typhoon conditions threaten Buckner Bay."

In addition to typhoon conditions it is also doubtful that any but the least prudent or disabled would want to ride out a 50-kt tropical storm in Buckner Bay. Accordingly 50 kt is herein used as the critical wind level for evasion planning purposes.

5.2 Discussions of Data Sets

The total data used consisted of the typhoon analog data set of tropical cyclone tracks and maximum winds. This set was used as the point of departure for forecast simulation and as a basis for estimating what winds actually occurred at Buckner Bay. This latter step was necessitated because observations are not routinely taken at Buckner Bay and those from observing stations in the vicinity are not considered representative (see Brand and Blelloch, 1976).

The record used includes all tropical cyclones from 1945-81 which passed within 360 n mi of Buckner Bay. There were in all 245 such tropical cyclones.

The maximum winds at Buckner Bay are estimated to have exceeded 100 kt on six occasions and typhoon force (including the above) on 32 occasions and to have exceeded 50 kt on an additional 29 occasions. This suggests typhoon force winds will be observed nominally once per year and storm force or above nearly twice per year. Those storms estimated to have caused at least 50 kt winds at Buckner Bay are listed in table 5.

From this data set over 13,000 forecasts were simulated and from the simulated forecasts wind probabilities were computed.

5.3 Results

Tropical cyclones passing Okinawa are quite different from those passing points farther south and east. They are a mixture of recurving and recurved storms. Most are near or past their peak intensity, consequently the major sources of impact uncertainty comes from the track and speed forecasts. Because, in the mean, passing tropical cyclones are mature and because of no important terrain influence, wind probabilities for Buckner Bay are high compared to other points studied. As a consequence, high threshold probabilites cover 95% of the actual damage cases. In this situation the performance of this type "CHARM clock" should be especially good.

Two sets of 95% or worst case arrival time lines were developed; one for 50-kt winds (figure 8) and one for typhoon force winds (figure 9). The former is expected to serve as a

Table 5. Tropical cyclones which are estimated to have caused strong winds at Buckner Bay. Given are month/year of occurrence, status at the time of closest point of approach (TS = tropical storm, TY = typhoon and ST = super typhoon, winds $\geq$ 130 kt), Name and Category of estimated winds at Buckner Bay (50 kt $\leq$ S $\leq$ 63kt and T of $\geq$ 64kt).

7/45	TY	OPAL	S	7/56	ST	WANDA	S	6/65	TS	CARLA	S
8/45	TS	EVA	S	8/56	TY	BABS	S	8/65	ST	JEAN	T
9/45	TY	IDA	T	9/56	ST	EMMA	T	8/66	ST	ALICE	T
10/45	TY	LOUISE	T	9/56	TY	HARRIET	T	9/66	ST	CORA	S
11/47	TY	FLORA	S	8/57	TY	AGNES	S	9/66	TY	ELSIE	S
10/48	TY	LIBBY	T	9/57	TY	FAYE	T	10/67	TY	DINAH	S
6/49	TY	DELLA	T	9/58	TY	HELEN	S	9/68	TY	DELLA	T
7/49	TY	GLORIA	T	8/59	TY	ELLEN	T	8/69	TY	CORA	T
7/50	TS	FLOSSIE	S	9/59	TY	SARAH	S	8/70	TY	WILDA	T
11/50	TY	CLARA	T	10/59	TY	AMY	T	9/70	TS	ELLEN	*
8/51	TY	MARGE	T	10/59	TY	CHARLOTTE	T	*	TS	FRAN	S
10/51	TY	RUTH	T	11/59	TY	EMMA	T	7/72	TY	RITA	T
6/52	TY	DINAH	T	11/59	TS	FREDA	S	7/73	TY	BILLIE	S
8/52	TY	KAREN	T	8/60	TY	TRIX	S	7/74	TY	GILDA	S
11/52	ST	AGNES	T	8/60	TS	CARMEN	S	8/74	TS	MARY	S
8/53	ST	NINA	S	9/61	ST	NANCY	T	7/76	TY	THRESE	S
8/54	TY	GRACE	T	10/61	TY	TILDA	T	9/77	TY	BABE	T
9/54	TY	MARIE	S	7/62	TY	JOAN	S	7/78	TY	WENDY	S
7/55	TY	CLARA	S	7/62	TY	NORA	T	8/78	TY	CARMEN	T
10/55	TY	OPAL	S	7/64	TS	FLOSSIE	S	10/79	TY	TIP	T
4/56	TS	THELMA	S	8/64	TY	KATHY	T				

*Tropical storms Fran and Ellen (1970) were in the final stages of merging as they passed over Okinawa.

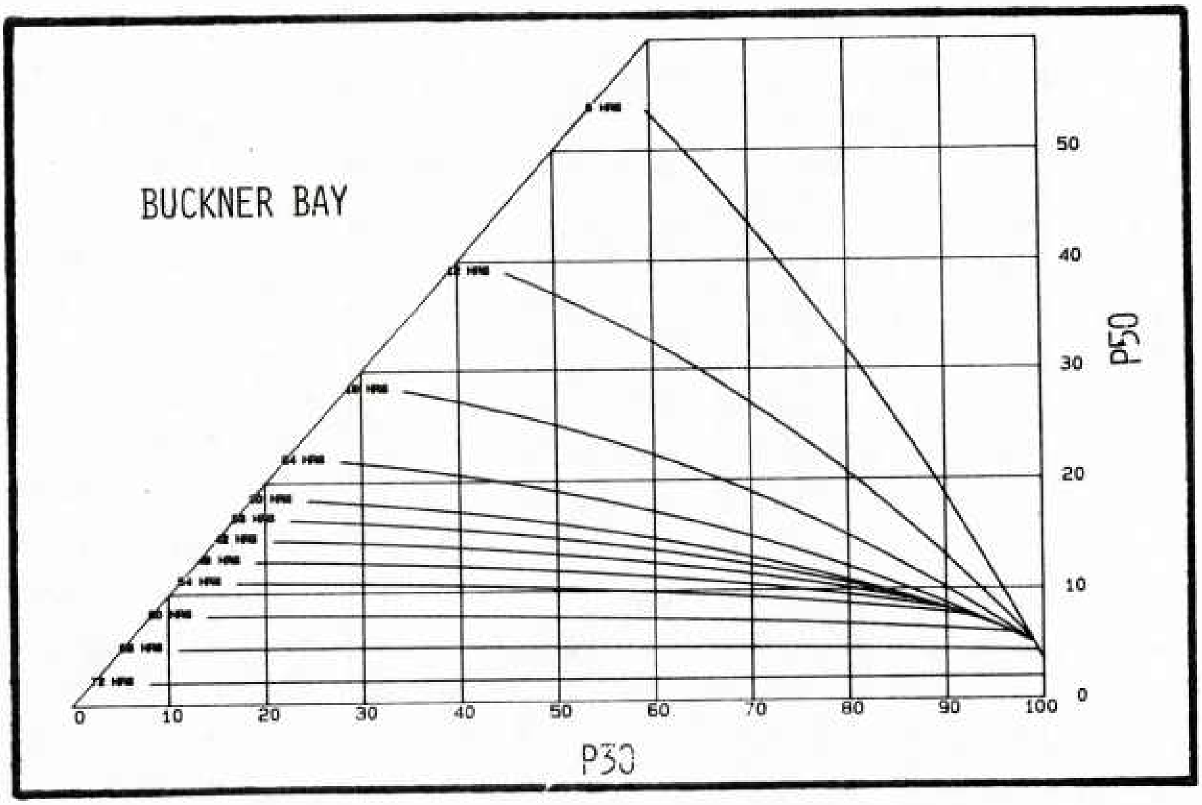

Figure 8. Buckner Bay, Okinawa CHARM clock for worst case (5%) arrival time of 50-kt (or greater) winds.

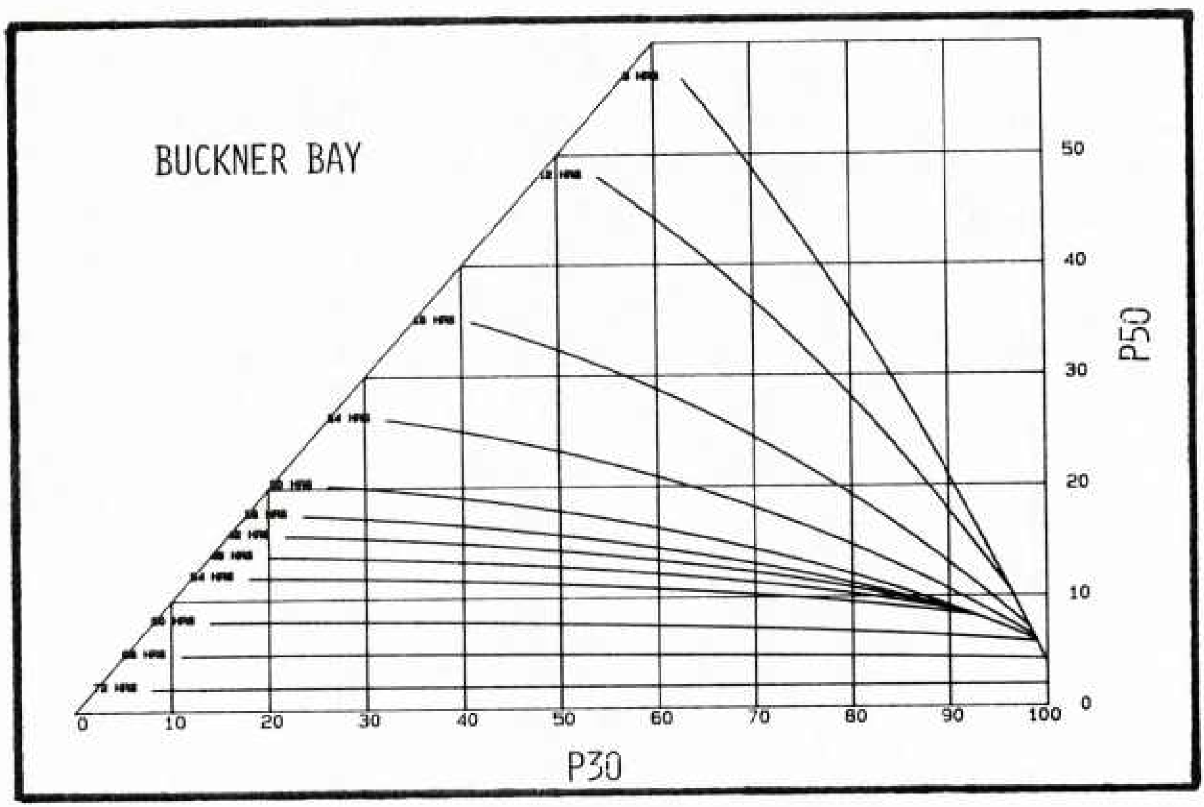

Figure 9. Buckner Bay, Okinawa CHARM clock for worst case (5%) arrival time of typhoon force winds.

guide to timing harbor evacuation while the latter is intended for more general typhoon condition setting. An attempt to apply them simultaneously will lead to minor ambiguities. For example, a P_{30}, P_{50} pair of (60,20) would lead to 50-kt tropical cyclone condition II and typhoon condition III. Higher probabilities will be required for a typhoon condition than for a lesser tropical cyclone condition of the same number. Deciding which to use can usually be based on the existing (as opposed to forecast) tropical cyclone intensity. If the tropical cyclone is a typhoon or nearly so on a steady or increasing trend, the typhoon condition is appropriate. If the cyclone is a depression or a weak tropical storm not expected to be a typhoon at CPA, the 50-kt tropical cyclone condition is appropriate. Most actions and the worst case time lines are about the same for the early conditions (III and IV) so the question most directly relates to conditions I and II and therefore a nowcast or a short range forecast is involved.

5.4 Overwarning

Table 6 shows overwarning rates for events in the simulated data set when various typhoon or 50-kt tropical cyclone conditions would have been set on the basis of exceeded threshold values. Thus the use of TCCSA for setting typhoon conditions I through IV results in satisfactory overwarning rates of 3.3, 5.7, 8.1, and 32.3 respectively. Use of TCCSA for 50-kt tropical cyclone conditions I through IV will result in much better rates of 1.6, 3.0, 4.6, and 15.7 respectively.

Table 6. Overwarning rates for occasions where typhoon and 50-kt tropical cyclone conditions would have been recommended.

	Typhoon Condition					50-kt TC Condition			
ACTUAL	I	II	III	IV	ACTUAL	I	II	III	IV
>63 kt	3.3	5.7	8.1	32.3	>63 kt	3.5	6.1	9.0	32.3
$\geq$50 kt	1.4	2.6	4.3	13.3	$\geq$50 kt	1.6	3.0	4.6	15.7
$\geq$34 kt	1.1	1.0	1.4	4.0	$\geq$34 kt	1.1	1.0	1.6	4.0

To put the overwarning rate in perspective, if a sortie is ordered on 50-kt tropical cyclone condition II a sortie would be ordered unnecessarily three times for each time it was (in hindsight) necessary.

6. YOKOSUKA, JAPAN

6.1 Discussion of Harbor Exposure

The following summary from Brand and Blelloch (1976) endorses Yokosuka as a typhoon haven.

"The conclusion reached in this study is that the port of Yokosuka is a 'safe' typhoon haven; a port in which to remain if already there or in which to seek shelter if at sea when threatened by a typhoon. The primary factors in reaching this conclusion are:

(1) The port provides shelter from wind and sea due to the surrounding land masses.

(2) Wave action induced by tyhpoons has been negligible in the port.

(3) Storm surge has negligible effect.

(4) The orientation of the berths and drydocks with respect to the local topography is good.

(5) The experience level and the high degree of competence of the Port Services personnel.

(6) The history of the port. Conversations with Japanese employees at Fleet Activities, Yokosuka indicated that since 1945 there is no recollection of U.S. Navy, Japanese Maritime Self Defense Force or merchant ships sortieing from the port of Yokosuka due to a typhoon.

(7) Except for carriers the only situation in which the port would not be a safe haven is when a very intense typhoon (> 120 kt) passed directly over or just to northwest (within 100 n mi) of Yokosuka. For carriers, if a berth shift to drydock six is not feasible, a sortie from

Yokosuka is recommended when Tropical Cyclone Condition of Readiness Three (48 hours) is set for sustained winds of 75 kt or greater at the Naval Oceanography Command Facility Yokosuka."

As will be discussed below, in the years of record here (1953-80) there was no case of sustained typhoon force winds observed at Yokosuka. Since we are developing methods based on that historical record we know at the outset that there will be no result which will recommend a typhoon condition. Accordingly a CHARM clock was developed for 50-kt tropical cyclone conditions I to IV.

6.2 Results

Tropical cyclones passing Yokosuka are quite different from those passing points farther south. They are dominated in numbers by mature and decaying storms embedded in the westerlies following recurvature. Consequently sources of impact uncertainity comes both from the size and strength forecasts as well as track and particularly speed forecasts. Included in the broad spectrum of decaying tropical cyclones which pass Yokosuka are occasional typhoons just passing their peak of severity as they pass. Ida (1958) and a second Ida (1968) are typhoons which had just peaked prior to CPA. Because in the mean passing tropical cyclones are decaying and because of terrain influence, wind probabilities for Yokosuka are low compared to Buckner Bay. However reasonable threshold probabilities cover 95% of the actual damage cases and the performance of the "CHARM clock" should be quite satisfactory.

Only one set of 95% or worst case arrival time lines were developed, that for 50 kt winds (figure 10). This is expected to serve as a guide to timing harbor repositioning or evacuation and is intended for more general condition setting.

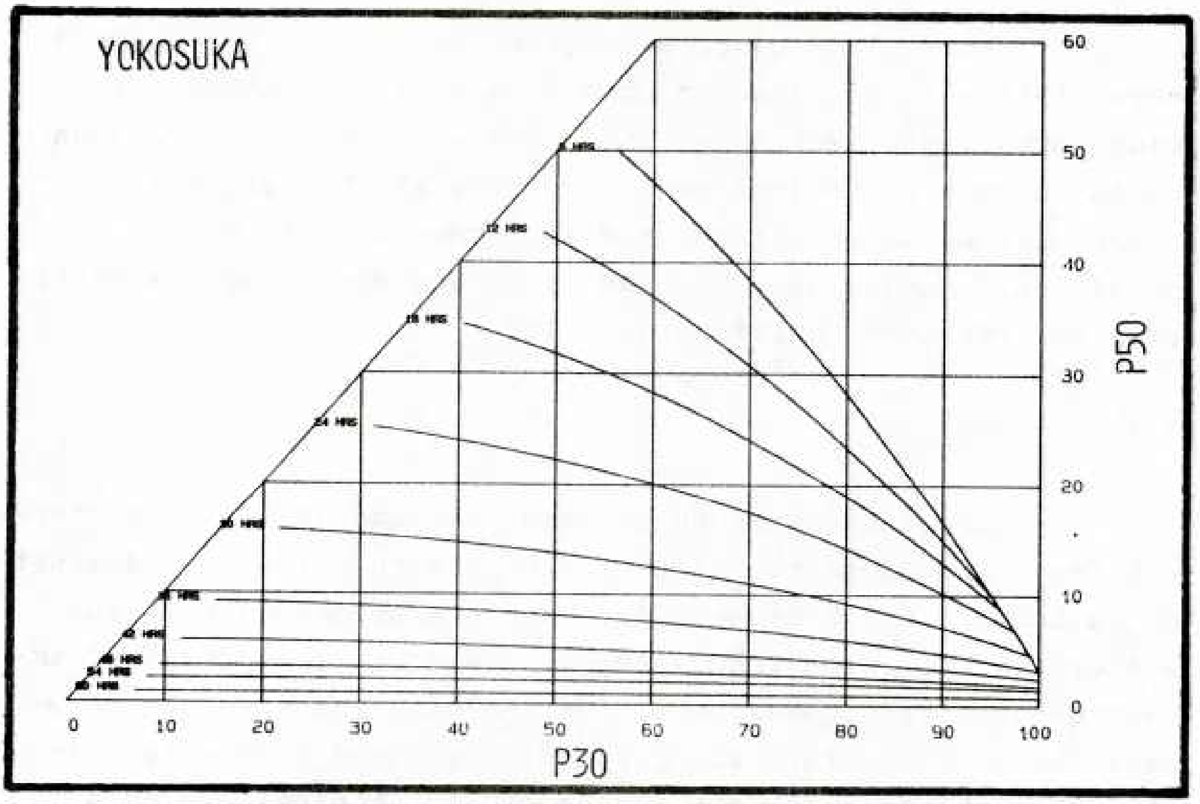

Figure 10. Yokosuka, Japan CHARM clock for worst case (5%) arrival time of 50-kt (or greater) winds.

Based on the history of past tropical cyclones it appears that a typhoon condition (for sustained typhoon force winds) is virtually never warrented at Yokosuka. This can be seen in table 7 where 50 kt is the maximum sustained (typhoon related) wind recorded over a 28 year period of observations at the very exposed NOCF location.

Table 7. Tropical Cyclones which caused maximum wind. Gusts in excess of Typhoon force at Yokosuka 1953-80. Given are date of passage, tropical cyclone status at time of passage (Tropical Storm = TS, Typhoon = TY) name, maximum sustained wind and peak gust. Also is shown the best track estimate of the cyclone maximum wind at CPA and its lifetime maximum and when the latter occured relative to CPA.

25 Sept. 53	TY TESS	40G74	65/150	- 78hr
11 Oct. 55	TY NORA	48G68	75/90	- 24hr
23 Jul. 58	TS ALICE	35G66	50/130	- 66hr
18 Sept. 58	TY HELEN	43G78	80/150	- 96hr
27 Sept. 58	TY IDA	50G96	70/175	- 24hr
27 Sept. 59	TY VERA	50G81	110/165	- 66hr
16 Sept. 61	TY NANCY	42G71	70/180	- 96hr
10 Oct. 61	TY VIOLET	47G74	60/180	- 66hr
29 Aug. 63	TY DELLA	45G71	70/100	- 42hr
25 Sept. 64	TY WILDA	42G76	65/150	- 84hr
18 Sept. 65	TY TRIX	48G83	75/130	- 66hr
25 Sept. 66	TY IDA	40G73	70/100	- 6hr
23 Aug. 69	TS CORA	37G70	40/ 85	- 72hr
19 Oct. 79	TS TIP	44G82	60/125	- 96hr

6.3 Overwarning

Table 8 shows overwarning rates for events in the simulated data set when various 50-kt tropical cyclone conditions would have been set on the basis of exceeded threshold values. Use of TCCSA for 50-kt tropical cyclone conditions I through IV will result in rates of 1.1, 2.3, 15.7, and 49.0. The overwarning rates for conditions I and II are excellent, those for conditions III and IV are quite high and suggest that the cost for 95% confidence is too high at these lead times.

Table 8. Overwarning rates for occassions where typhoon and 50-kt tropical cyclone conditions would have been recommended.

	50-kt TC Condition			
ACTUAL	I	II	III	IV
≥50 kt	1.1	2.3	15.7	49.0
≥34 kt	0.1	0.3	1.4	1.9

To put the overwarning rate in perspective, if a harbor vessel shifting or a sortie is ordered on 50-kt tropical cyclone condition II, they would be ordered unnecessarily two times (2.3 in Table 8) each time they were (in hindsight) necessary.

7. SUBIC BAY

7.1 Discussion of Harbor Exposure

The following is the summary description by Brand and Blellock (1976) concerning Subic Bay as a possible typhoon haven.

"Previous texts classifying Subic Bay as a typhoon haven have done so with certain reservations or qualifications. It is true that many ships have successfully weathered the numerous typhoons which have affected Subic Bay. However, it is also a fact that Subic Bay has never really been tested by the passage of a truly severe tropical cyclone. Those storms whose eyes have crossed directly over Subic Bay have been relatively weak storms; in the case of severe tropical cyclones the eyes have only come close, with the strongest winds missing Subic Bay by 50-100 n mi, and the remaining winds being further reduced by the topography of the surrounding terrain. The highest sustained wind recorded during the period 1955-1973 was 56 kt.

In any event, it is felt that the potentially most dangerous situation is not presented by a cyclone passing directly over Subic, but rather by a close south-southwestward passage between 15-50 n mi. Consider a case where a cyclone has crossed the Philippines through the San Bernardino Strait, losing little of its intensity, and then moves northward (perhaps starting to recurve), so that the eastern and southern portions of the wall cloud and feeder band activity have unobstructed access to the bay.

After considering the above facts and after many discussions with experienced personnel at Subic Bay, it is the conclusion of this study that, although Subic Bay does provide some degree of shelter from typhoon passage, it should not be considered an "unqualified" typhoon haven. The sheltering effect provided by the surrounding terrain qualifies Subic Bay as a much safer port in heavy weather than Hong Kong, Kaohsiung, or Chilung (Keelung). However, large combatants (CVA, cruisers, etc.) would find the relatively small size of Subic Bay restrictive. The cost in terms of time and money of evasion would be small since the evasion routes are short and direct. Smaller craft, given ample warning time, should also be able to evade into the navigable semicircle. If ample warning time is not given, or the means to evade does not exist, relatively safe typhoon anchorages are present in the inner basin of Port Olongapo for a limited number of small vessels. Also certain anchorages close to the western shore of the bay provide some degree of shelter."

7.2 History of Typhoons Passing Subic Bay

From mid-1955 through 1979 there were 17 occasions (hourly observations) where 34 kt winds (or greater) were observed at NAS Cubi Pt. Most (but not all) of these were associated with tropical cyclones. Woo et al. (1978) shows that for certain wind directions, portions of Subic Bay will receive substantially higher wind speeds than Cubi point. That study only covered winds from the SW quadrant. Cubi Pt. is well exposed to winds from the NNW through East and well protected by a nearby hill from winds out of the SE quadrant. Accordingly table 9 was developed to approximate the maximum wind in Subic Bay as a function of the Cubi Point wind.

Table 9. Estimate of ratio of maximum winds in Subic Bay to Cubi Point winds

Dir	Maximum Wind	Dir	Maximum Wind
N	1.10	S	1.22 *
	1.00		1.28 *
NE	1.00	SW	1.08 *
	1.00		1.16 *
E	1.25	W	1.70 *
	2.00		1.35
SE	2.00	NW	1.10
	2.00		1.00
S	1.22 *	N	1.10

* from Woo et al. (1978)

These were then applied as correction factors to the Cubi Point wind (actual Cubi Point wind was multiplied by these direction dependent values) to estimate the maximum wind in the Bay.

Microfiche records of Cubi Point observations for the years 1956 through 1980 were obtained and maximum sustained winds were estimated for Subic Bay by adjusting according to Table 9. During that 25 year period 216 tropical cyclones (8+ per year) passed within 360 n mi of Subic, most with little or no effect, except indirectly by either enhancing or retarding the existing monsoon circulation. However, in 45 cases (21%) gale force winds are estimated to have occurred. Winds over 50 kt occurred in 13 cases (6%) and 3 (1%) probably caused typhoon force winds somewhere in Subic Bay. Table 10 lists those tropical cyclones causing (by our estimate) at least 50 kt winds in Subic Bay.

Table 10. Tropical cyclones estimated to have caused at least 50-kt winds at some point in Subic Bay. Given are the name (if known) date and estimated maximum sustained wind.

Name	Date	Wind	Name	Date	Wind
UNK	8/15/57	SSE69	FAYE	10/10/71	W59
UNK	10/13/57	SSW57	BILLIE	7/14/73	W50
WINNIE	6/30/64	SSE80	NORA	10/08/73	WSW51
IDA	8/07/64	SW50	RUTH	10/16/73	SSW56
IRMA	5/19/66	SSE64	NADINE*	8/15/74	W58
EMMA	11/04/67	SSW51	IRMA	11/28/74	W59
PATSY	11/19/70	NNE55	LOLA	9/27/78	E53

*Nadine 1974 did not pass within 360 mi of Subic Bay recurving East of northern Luzon.

Ideally we would like to develop a method to reliably identify these over 50-kt cases without excessive overwarning. That effort is the subject of the next section.

The Typhoon Haven summary (Brand and Blelloch, 1976) is heavily (and properly) based on "local" opinion and is not borne out by the meteorological evidence of rare occasions of strong winds which might suggest that Subic Bay is a typhoon haven. However, non-meteorological factors such as size of the bay, orientation of berths, holding quality of the bottom of the bay and the ease of evacuating are factors which generally favor evacuation. Since meteorological factors do not determine the typhoon haven worthiness of the port, they also do not (in the mean sense) discriminate severity between threatening situations. The most dangerous situations historically have been those which pass nearly over or north of Subic since they presumably reinforce the southwest monsoon (see figures 11 and 12). Those which pass south of Subic have often resulted in

improved weather since they either re-establish the northeast monsoon or at least set up a temporary easterly flow and therefore a downslope regime. Figure 11 shows the tracks of tropical cyclones which caused at least 50 kt winds at Subic. Within the southwest monsoon strong pressure gradients and gale force winds are not uncommon. A further tightening of the pressure gradient by a tropical cyclone even of modest intensity could cause storm force winds in Subic Bay. Storm force winds represent potential damage to piers if large ships are moored in beam wind situations. In this scenario the severity of the tropical cyclone is of secondary importance but its size may play a major role. At any rate wind probabilities do not distinguish these cases very well.

Figure 12 shows the position of all passing tropical cyclones relative to Subic Bay when the maximum winds associated with the passage occurred at Subic. Note that except for a few "direct hits" stronger winds are always associated with storms located northwest clockwise through east of Subic. Conversely many strong storms in that same sector did not cause strong winds at Subic.

Figure 13 shows a scatter of monsoon strength versus storm distance north of Subic's latitude when maximum winds occurred. Monsoon strength is estimated by the average of the northeast components of hourly winds 12, 24, 36, and 48 hours before CPA. Note that a large negative number would represent a strong southwest monsoon typical of the typhoon season. Contrary to the usual opinion monsoon strength (as measured above) seems to be a poor indicator of wind strength at Subic associated with tropical cyclone passage.

Figure 14 shows a scatter of central winds in a typhoon with distance north of Subic's latitude when maximum

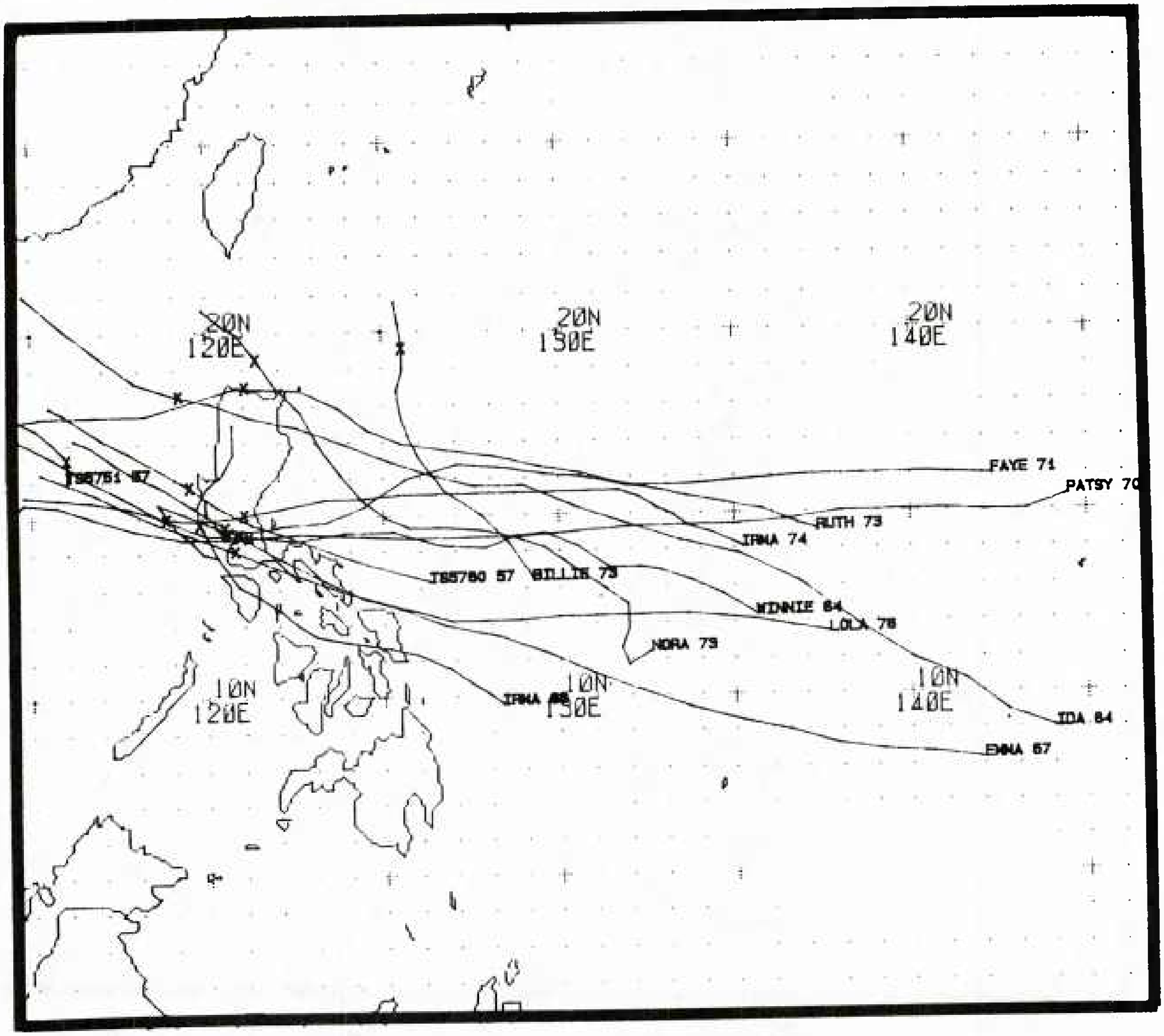

Figure 11. Tracks of tropical cyclones passing within 360 nm of Subic Bay and are estimated to have causes at least 50 kt winds in the bay. "x" Designates cyclone location when maximum wind occurred at Subic.

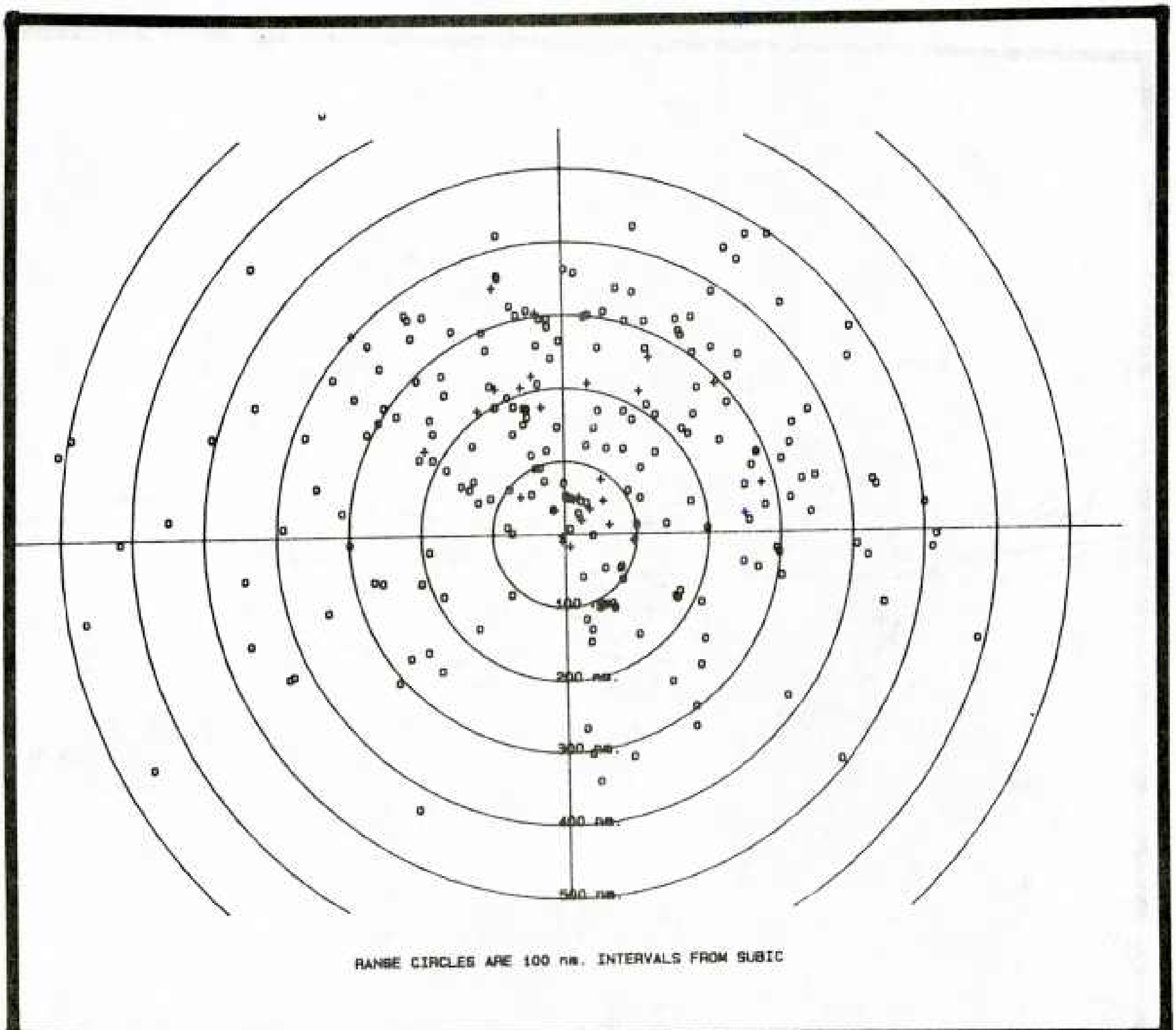

Figure 12. Depiction of location of tropical cyclones where maximum wind occurred in Subic Bay. "+" means maximum was over 40 kt.

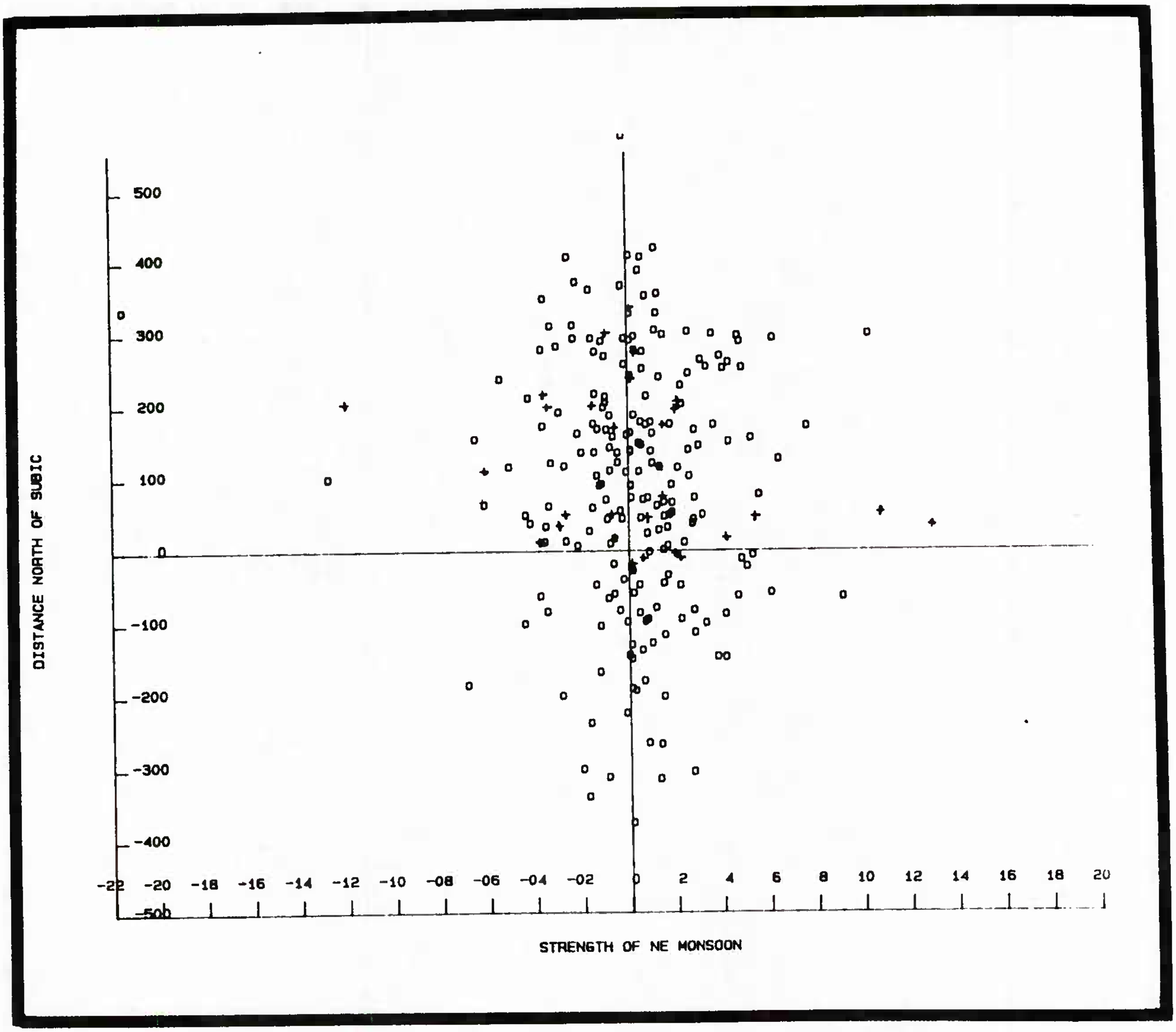

Figure 13. Same cases as figure 12 plotted versus strength of monsoon (plotted on abscissa, defined in text) and distance north of Subic's latitude (as in figure 12).

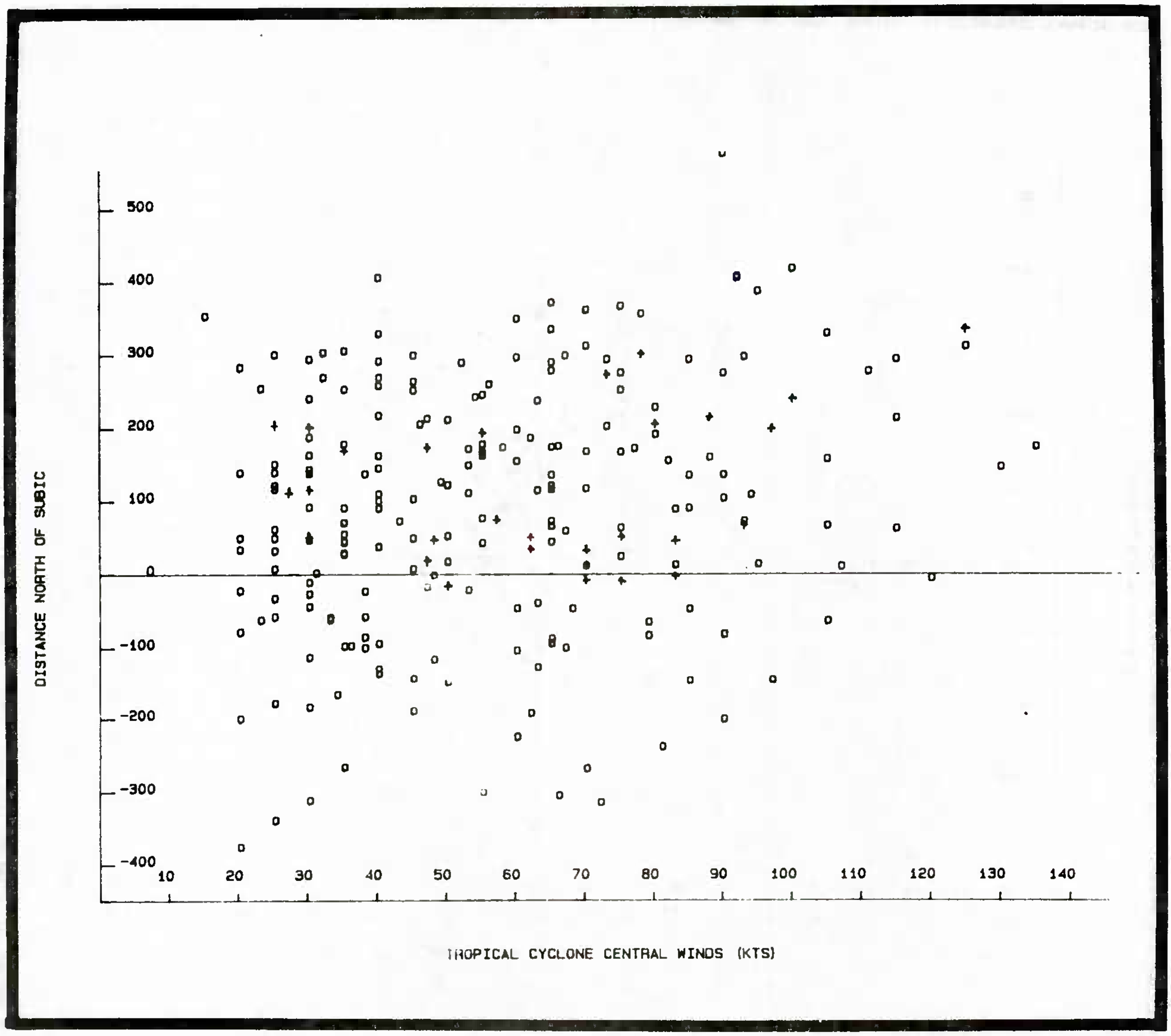

Figure 14. Same as figure 13 except abscissa is central winds in the tropical cyclone at the time of CPA.

winds occurred at Subic. It is clear that central typhoon winds have little relationship to winds observed at Subic.

7.3 Results

Simulated forecasts were made for the 216 tropical cyclones that approached within 360 n mi of Subic Bay. Forecasts were initiated independently several times at each 6 hourly position along the actual tropical cyclone tracks. The 30- and 50-kt wind probabilities were computed for Cubi Point and for Subic Bay from each forecast. The Subic Bay probabilities were computed by first applying directional adjustments from Table 9 to a terrain modification package for Cubi Point.

The wind probabilities for both Cubi Point and Subic Bay had, as expected, little discriminating power relative to the occurrence of 50 kt winds in Subic Bay. Using these probabilities would result in an overwarning factor of around 15-20 in setting a 50 kt tropical cyclone condition II with a 95% confidence. This compares to an overwarning rate of 3 or 4 for the other WESTPAC stations studied herein.

Therefore a CHARM clock is not considered useable for Subic Bay. This does not mean that wind probabilities are either useless or unreliable. They indeed appear to reliably reflect the rarity of 50 kt winds observed at Cubi Point and the apparent randomness with which passing tropical cyclones cause strong winds in Subic Bay.

8. PEARL HARBOR

8.1 Discussion of Harbor Exposure

The following is the summary description by Gilmore and Jarrell (1984) concerning Pearl Harbor (and Honolulu) as hurricane havens.

"The location of the Hawaiian Islands in a region of tropical cyclone activity, the lack of sheltered facilities, and potential vulnerability to storm surge make Pearl and Honolulu Harbors poor hurricane havens. Evasion at sea is recommended for all seaworthy deep-draft vessels and submarines when the south coast of Oahu is threatened by an intense tropical storm or hurricane."

In consultations with meteorologists representing COMTHIRDFLT, CINCPACFLT and NAVWESTOCNCEN it was determined that the desirable wind level for setting conditions is 35-kt sustained or equivalently (using a 1.4 gust factor) 50-kt gusts. In the following discussion the notation 35G50 will be used to indicate a condition where either 35-kt (or greater) sustained winds or 50-kt (or greater) gusts were observed.

8.2 Discussion of Data Sets

The tropical cyclones passing the Hawaiian islands are very well documented by Shaw (1981) and NOAA technical memoranda PR-22 (1981), PR-25 (1982), PR-27 (1984) and PR-29 (1985) covering the years up to 1978, 1980, 1981, 1982, and 1983 respectively. A total of 32 tropical cyclones have posed a realistic threat to the Pearl Harbor vicinity of Oahu since

the mid 1800s. Of these 5 are estimated to have caused at least 35-kt sustained winds or 50-kt gusts along the Oahu south coastal area. These are listed in Table 11.

Table 11. Tropical cyclones estimated to have caused 35G50 winds in the Pearl Harbor area.

Name	Date	Honolulu Max Wind		Remarks
H. NINA	12/02/57	NE	45G62	Wind Gust 71 (Shaw p39)
T.S. UNNAMED	8/08/58	ENE	30G36	Winds 35G50 (Shaw p40)
H. DOT	8/07/59	ESE	45G56	
T.D. IRAH	9/17/63	SE	35G43	
H. IWA	11/23/82	SSW	40G70	

Since records are good back to about 1950 there is a required frequency of about one sortie per seven years. A reasonable amount of overwarning would probably cause a sortie every two years or so. The study has as its objective providing guidance that will permit condition setting with a high degree of confidence without excessive overwarning.

8.3 Results

Tropical cyclones passing Pearl Harbor are in a climatologically hostile area, and so the major problem is predicting the intensity trend. Since most cyclones are dissipating, a downward trend is the norm and those that influence Oahu generally either dissipate slower than normal or even maintain or increase their strength. Thus, although track and speed forecasts are by no means easy in the central Pacific, the size and intensity forecasts are the most troubling sources of forecast uncertainty. Wind probabilities are especially low for Pearl Harbor because winds are typically weak. This, and the policy

of executing a sortie for 35-kt winds dictate that CHARM thresholds be particularly low. Nevertheless the performance of the "CHARM" clock should be satifactory.

Two sets of worst case arrival time "CHARM clocks" for 35G50 winds were developed, one for 95% confidence and the other for 90%. These are shown in figures 15 and 16. They are entered with 30-kt and 50-kt 72 hr elapsed time (or time integrated) wind probabilities.

8.4 Overwarning

Table 12 shows overwarning rates for events in the simulated data set when various 35G50 tropical cyclone conditions would have been set on the basis of exceeded threshold values.

Table 12. Overwarning rates for occasions 35G50 tropical cyclone conditions would have been recommended.

	35G50 TC Condition			
	I	II	III	IV
90% Conf	1.4	0.9	1.5	4.9
95% Conf	1.3	1.0	1.6	6.7

To put the overwarning rate in perspective, if a sortie is ordered on 35G50 tropical cyclone condition II, a sortie would be ordered unnecessarily only once (0.9 or 1.0) each time it was (in hindsight) necessary.

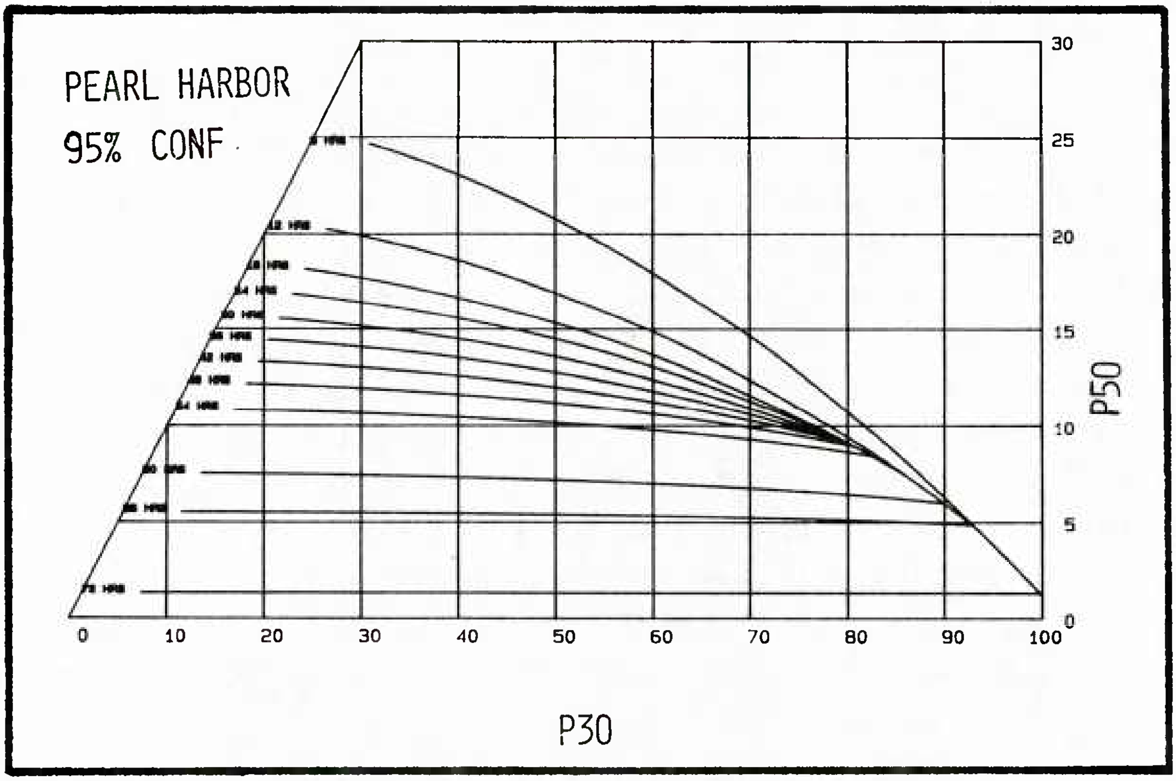

Figure 15. Pearl Harbor, Hawaii CHARM clock for worst case (5%) arrival time of 35G50 winds.

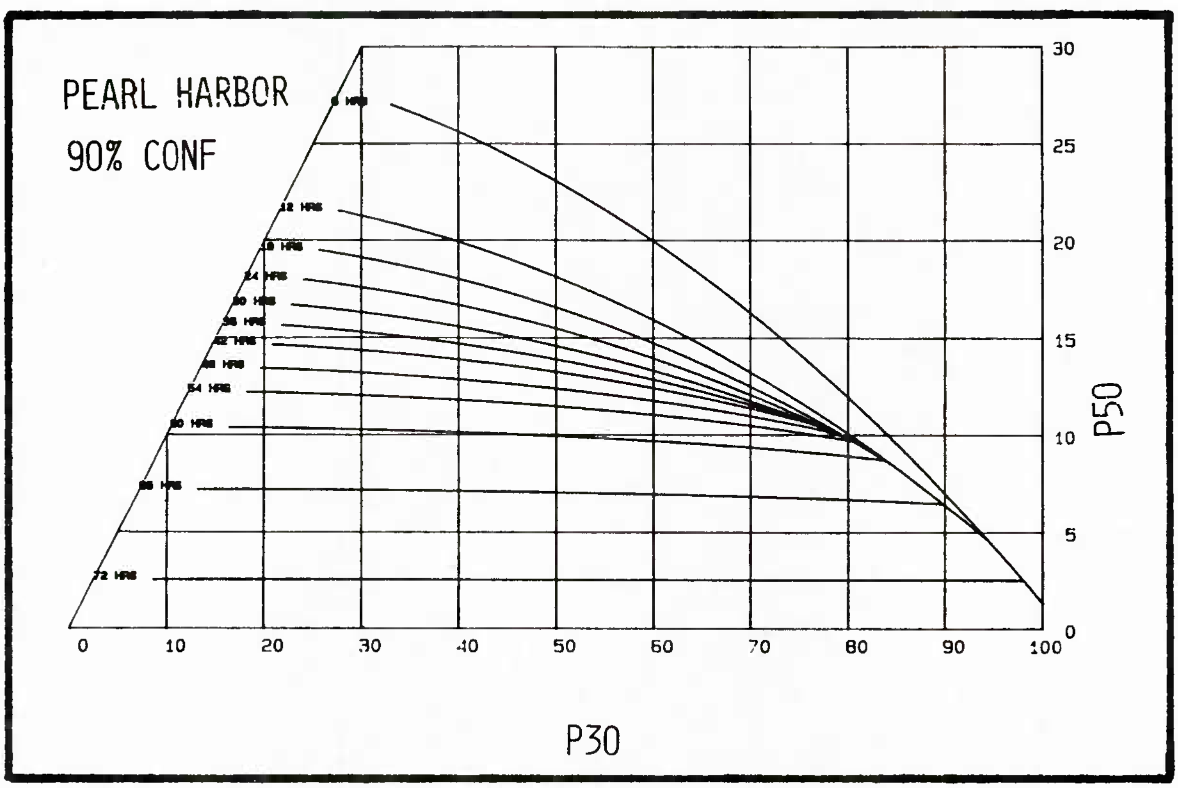

Figure 16. Pearl Harbor, Hawaii CHARM clock for worst case (10%) arrival time of 35G50 winds.

9. CONCLUSIONS

Studies were made to apply the CHARM methodology and wind probabilities to assist in the timing of tropical cyclone readiness condtions. Of five points studied (Apra Harbor, Guam; Buckner Bay, Okinawa: Pearl Harbor, Hawaii; Subic Bay, Philippines and Yokosuka, Japan) successful completion of CHARM "clock" nomographs was realized in four cases. In the fifth case, Subic Bay, excessive overwarning would result from using the "best CHARM clock". Comparable overwarning is probably the case now for the present subjective methods primarily because non-meteorological considerations dominate the decision process at Subic. For the four successful points, the overwarning rates appear to be very reasonable and the CHARM "clocks" should be quite useful.

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